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A PRELIMINARY ATTEMPT TO DEVISE A TEST OF THE ABILITY OF HIGH SCHOOL PUPILS IN THE MENTAL MANIPULATION OF SPACE RELATIONS

H. N. IRWIN
Fairmount Junior High School
Cleveland, Ohio

With the appearance in recent years of a number of studies in space perception and visual imagery[1], teachers of high school mathematics have become increasingly aware of the part played in this subject by the pupil's ability to perceive, remember, analyze, and work over in imagination space relations of two and three dimensions. A brief survey of almost any classroom situation in which goemetrical mathematics is the subject of study reveals the fact that the pupil's success or failure is conditioned to no small extent by his ability to "see the figure," to rearrange the parts of a figure, to construct in imagination essential but missing parts of a figure, to hold certain elements of the figure or situation in mind while adding or taking away others. Familiar illustrations of this fact are the pupil's inability to construct a parallelogram on a given triangle, or a triangular prism on a given triangular pyramid; his difficulty in "turning figures over" so that corresponding parts lie in corresponding positions; his inability to read off the correct proportions from two similar figures when not similarly placed with respect to each other.

[1] Judd, C. H., and Cowling, D. J., Studies in Perceptual Development. Psychological Monographs, Vol. VIII, No. 3, Pp. 349.

Judd, C. H., Psychology of High School Subjects. Ginn & Co. 1915.

Rugg, H. O., Experimental Determination of Mental Discipline in School Studies. Warwick & York. 1916.

Nor is the exercise of this ability to deal with space relations limited to the field of geometrical mathematics. The pupil in general science is called upon to use space imagery when he reads that the suction pump works as follows:

" . . . As the handle is forced downward, the plunger rod and plunger are raised. The water which is already above the plunger, or bucket, is lifted till it stands higher than the spout, out of which it runs.

" . . . . as the plunger is raised there is a tendency to produce a vacuum just beneath it. The atmosphere pressing down upon the surface of the water in the well forces the water up the run and through the inlet valve to fill the vacuum . . . . "[1]

The pupil in sewing may find frequent need of spatial imagery as witness the following description of how to make a muff:

" . . . . Cut a piece of muslin 7 inches long and 3¼ inches wide. Lay this piece on the silk that you are to use for the lining and baste it lightly on. Then cut the lining all around, being sure that it is a quarter of an inch larger on every side than the muslin. Fold this quarter of an inch of silk over the muslin and baste it. The next thing to do is to make the trimming to go around the edge of the muff. . . . . If you use silk, cut a piece one inch wide and about 30 inches long. Fold it in the middle lengthwise and gather where the two edges come together. Then baste this gathered ruffle around the two long sides and one short side of the piece you have just made, being sure to baste it on the same side you basted the lining. Now for the outside of the muff. . . . . If you use velvet cut the piece 7 inches by 3¾ inches and turn in the edges half an inch. Sew the outside piece neatly to the gathered edge. When you have done this, fold in the shape of a muff and fasten the narrow ends together, leaving the end with the ruffle on the outside."[2]

Again the pupil in English, it would seem, must make use of some form of space ideas if he is to appreciate such literary passages as the following:

"The mill where Will lived with his adopted parents stood in a falling valley between pinewoods and great mountains. Above, hill after hill

[1] Barber, Fuller, et al. General Science, pp. 476. Cf.—Construction of the Water Meter, pp. 496; The Four-cycle Engine, pp. 577.

[2] Edna A. Foster: Something to Do, Girls, pp. 36.

soared upwards until they soared out of the depth of the hardiest timber, and stood naked against the sky. Some way up a long gray village lay like a seam or rag of vapor on a wooded hillside; and when the wind was favorable the sound of the church bells would drop down, thin and silvery to Will. Below, the valley grew ever steeper and steeper and at the same time widened out on either hand; and from an eminence beside the mill it was possible to see its whole length and away beyond it over a wide plain, where the river turned and shone and moved on from city to city on its voyage towards the sea."[1]

Or finally the man who has just purchased his first automobile and is glancing through the instruction book will find occasion to use space imagination in some measure as he reads such paragraphs as this on how to adjust the carburetor:

"1. Turn gasoline adjustment to the right until needle valve is completely closed. 2. Set air adjusting screw so that the end of the screw is even with the point of the ratchet spring just above it. 3. Open gasoline adjustment by giving needle valve one full turn. 4. Start motor as usual; with air regulator turned to "Hot" until motor is thoroughly warmed up. 5. With the spark lever fully retarded turn gasoline adjustment to the right closing needle valve until motor idles smoothly. 6. Advance the spark lever and turn air adjustment screw to the left, a little at a time, until the motor begins to slow down or skip, indicating too much air; then turn to the right until the motor runs smoothly."[2]

These random illustrations out of a large number that might easily be cited serve to emphasize in a concrete way the importance and wide application of the ability to perceive and rearrange in imagination spatial data and relations. The moment our attention is drawn to the need for this ability in some form in so many different lines of pupil activity a number of questions immediately arise to our minds. We are interested in knowing when this ability normally begins to develop, to what extent it may be trained, what sorts of training material are necessary or most effective and economical. More particularly those of us who are conducting high

[1] Robert Louis Stevenson: Will O' the Mill, pp. 1.

[2] Buick Motor Co., Instruction Book, 1917, pp. 27.

school courses wish to know to what extent any given training material in mathematics, drawing, or other school course developes or trains its pupils in either specific or general ability to deal with space relations.

It was with these and related questions in mind that the present attempt was made to devise some sort of class test that should yield a rough measure of the ability of each pupil in a class to image space relations. It was, of course, realized from the start that any class test consisting of questions to be read and answered by the pupils in class must involve other factors than the particular ability which it was desired to measure. One of the most significant of these factors would necessarily be the ability of the pupil to read. But it was hoped that such factors might prove, in classes of high school rank, to be more or less constant in both preliminary and final tests, thus leaving the ability to deal with space as a fairly accessible element of the pupil's mental reactions.

The first step in the study was the formulation of a number of questions. Some, as will appear, were suggested by questions to be found in other tests,[1] while the remainder were taken from everyday experiences in and out of the classroom. Each question involved in its answer the imaging of objects and relations in two or three dimensional space. Only such questions were selected as dealt with objects and relations perfectly familiar to high school pupils and the wording in each question was made as clear and simple as possible. A

[1] Healy, W., and Fernald, G. M. Tests for Practical Mental Classification. Psychological Monographs, Vol. XIII, No. 2.

Kent, G. H. A Graded Series of Geometrical Puzzles. Journal of Experimental Psychology, Vol. I, pp. 41.

Pintner and Paterson: A Scale of Performance Tests. D. Appleton & Co., 1917.

Rogers, A. L. Experimental Tests of Mathematical Ability and their Prognostic Value. Teachers College, Columbia University, 1918.

Rugg, H. C. Experimental Determination of Mental Discipline in School Studies. Warwick & York, 1916.

Terman, L. M. Measurement of Intelligence. Houghton, Mifflin Co. 1916

Whipple G. M. Manual of Mental and Physical Tests.

trial set of 34 such questions was drawn up and given under regular test conditions to three high school classes, one in second year mathematics, one in third year, and one in fourth year. A careful study of the results secured from this first set of questions was made with a view to eliminating such defects as came to light in the wording or subject matter of each question. On the basis of these findings two new sets of questions, called test A and test B, given below, were drawn up. The two sets were made of as nearly the same difficulty as was possible at this point in the study.

Test A was now given as a pre-training test to 13 classes in first and second year high school mathematics selected at random in four different high schools. The total number thus taking test A was 337. Using the answers thus obtained the score to be assigned to each question was determined on the assumption that the abilities involved in the test were distributed in accordance with the normal probability curve in these classes. In the same way test B was given as a pre-training test to 13 other classes similarly chosen from the same schools. The total number thus taking test B was 352. As in test A the answers thus obtained were used to determine the score to be assigned to each question in test B. These pre-training tests were followed by a "training interval" varying in length from 10 days to 4 months for the different classes, during which interval the pupils in each class pursued their regular studies under normal school conditions. At the close of this training interval test B was given to 10 out of the 13 classes that had taken test A previously while test A was given to 10 out of the 13 classes that had taken test B previously.

While the entire study was frankly of a preliminary nature it was hoped that some results might be secured from these tests which would be of value in the final formulation of a series of test questions. Individual and class scores in both the pre-training and post-training tests were therefore

computed and a number of correlations worked out. A brief study of this material however sufficed to show that it was of minor value in determining how far particular questions might be used in the final series. On the other hand it soon became apparent that the pupils' errors were of no little significance in revealing the character of the mental processes involved in answering particular questions. For this reason a careful study of all the incorrect answers in the pre-training test papers was made in order to determine the nature and frequency of the errors that had occurred. The results of this study are given in brief in the comments following each question of test A and test B. The principal types of errors thus found to recur are then presented in the summary following test B. The net outcome of the calculations just referred to and of the study of errors has been the construction of two new sets of questions, presented at the close of this report as test C and test D, in which a number of the questions used in tests A and B have been omitted, several have been reworded, and a number of questions included that were not used in tests A and B.

In the two lists of questions immediately following, comprising test A and test B, the errors are noted in the order of frequency with which they occurred. The suggested explanation of each of these is only a suggestion though stated arbitrarily and without constant repetition of the "perhaps" or "probably" which should precede each such suggestion. Where the question is changed or omitted in the revised tests, test C and test D, this fact is noted with accompanying explanation.

(*To be concluded in November*)